Auditory evoked magnetic fields in patients with loudness recruitment phenomenon

T. Morita[1], Y. Naito[1], T. Nagamine[2], N. Fujiki[1,3], H. Shibasaki[2], and J. Ito[1]

[1]*Department of Hearing and Speech Science, Graduate School of Medicine, Kyoto University, 606-8507, Kyoto, Japan;* [2]*Department of Brain Pathophysiology, Graduate School of Medicine, Kyoto University, 606-8507, Kyoto, Japan;* [3]*Brain Research Unit, Low Temperature Laboratory, Helsinki University of Technology, FIN-02015 HUT, Finland*

1 Introduction

Loudness recruitment is a phenomenon observed in patients with inner-ear hearing loss who exhibit an abnormally rapid rise in loudness sensation with a small increase in sound stimulus intensity. Although the hearing threshold is elevated in such patients, loudness sensation approximates or equals that of subjects with normal hearing at high stimulus intensities. Many such patients feel more uncomfortable than normal-hearing subjects when they hear loud sounds. To elucidate the cortical representation of this phenomenon, we measured auditory evoked magnetic fields (AEFs) in patients who had mild to moderate inner-ear hearing loss with loudness recruitment, and compared results with those for normal-hearing subjects.

2 Methods

2.1 Subjects

Ten patients with inner-ear hearing loss were studied (8 males, 2 females; 19-75 years of age, mean age 53). All patients had loudness recruitment (5 bilateral, 4 left ear and 1 right ear). The etiologies of inner-ear hearing loss were sudden deafness, Meniere disease and unknown sensorineural hearing loss. SISI (Short increment sensitivity index) test ≥ 70% at 1kHz was considered phenomenon-positive.

The control group consisted of 9 healthy adults (9 males; 24-36 years of age, mean age 28) with normal audiograms (hearing thresholds ≤ 20 dB HL for frequencies 250 - 4000 Hz). All subjects were right-handed. All subjects gave informed consent to participate in this study.

2.2 Stimulus and analysis

The sound stimulus used was a 1 kHz pure tone, which was presented monaurally through a plastic tube. The duration of the sound stimuli was 200 ms (15 ms linear rise/ fall times), and intensity was set at 40, 50, 60 or 70 dB HL (hearing level). The sounds with four different intensities were presented randomly and equiprobably within a single sequence to each ear with a constant 1-s ISI. We instructed the subjects to ignore the stimuli. AEF was recorded with a 122-channel whole-head neuromagnetometer (Neuromag Ltd.). The recording passband was 0.03-130 Hz, and data were digitized at 419 Hz. The analysis period was 950 ms, from 150 ms before to 800 ms after the stimulus onset. The 100 ms pre-stimulus segment was used as the baseline for amplitude measurment. The vertical electro-oculogram (EOG) was used to reject data contaminated by eye movements and blinks. One hundred epochs were averaged for each stimulus. After digital low-pass filtering at 40 Hz, two equivalent current dipoles (ECDs) were used to explain the magnetic field distribution.

2.3 Three-dimensional MR imaging

All subjects underwent three-dimensional MR imaging. A single sphere model was used for the source modeling. Each subject's sphere was determined from one's own MRI data.

3 Results

3.1 Auditory evoked fields

Figure 1 shows responses of a representative patient from channels showing the largest amplitudes over temporal areas with four different stimulus sound intensities. This patient had 50 dB HL hearing loss in the left ear. There was no response at either 40 or 50 dB HL. As sound intensity was increased to 60 or 70 dB, amplitude increased dramatically and latency decreased.

Figure 2 shows responses of a representative normal subject. The difference in amplitude and latency among stimulus intensities was not as prominent as in patients.

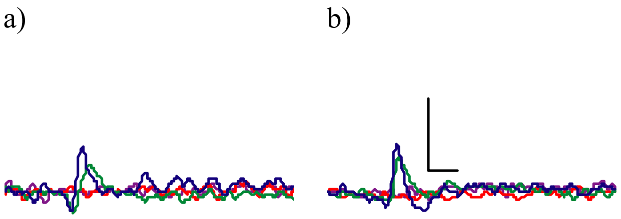

Figure 1: *Responses of a patient in the channel with the largest amplitudes over temporal areas (left-ear stimulation). a) Left hemisphere. b) Right hemisphere. Sound intensity was 70 (Blue line), 60 (Green line), 50 (Red line) or 40 (Purple line) dB HL. Vertical bar shows 100 fT/cm, horizontal bar 100 ms.*

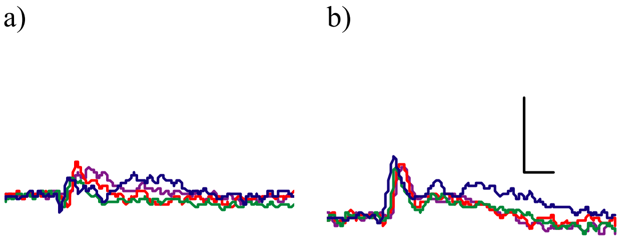

Figure 2: *Responses of a representative normal subject in the channel with the largest amplitudes over temporal areas (left-ear stimulation). a) Left hemisphere. b) Right hemisphere. Sound intensity was 70 (Blue line), 60 (Green line), 50 (Red line) or 40 (Purple line) dB HL. Vertical bar shows 100 fT/cm, horizontal bar 100 ms.*

In seven out of ten patients, significant responses were recorded at intensities as low as 5 to 10 dB above the hearing threshold, as in the above-described patient. On the other hand, significant responses in normal subjects are usually recorded at 30 dB above the threshold or higher [1].

3.2 Dipole moment of N100m

The ECD moment of N100m increased as a function of sound intensity in both groups, except in the hemisphere ipsilateral to the stimulated ear in normal subjects. Over both hemispheres, the dipole moment was larger for contralateral than for ipsilateral stimuli.

The dipole moment at high stimulus intensities was larger in patients than in normal subjects. In addition, the degree of increase in the moment was much larger in patients than in normal subjects, particularly in the contralateral hemisphere (see Tables 1 and 2).

Table 1: *Mean dipole moments of N100m ECD in normal subjects and patients (left-ear stimulation). S.D.: standard deviation*

a) Left hemisphere.

	Normal subjects (n=9)		Patients (n=9)	
Intensity [dB HL]	Moment [nAm]	S.D.	Moment [nAm]	S.D.
40	13.5	4.3	-	-
50	10.4	4.2	12.7	9.9
60	8.8	4.7	16.5	9.3
70	12.1	2.3	23.4	12.6

b) Right hemisphere.

	Normal subjects (n=9)		Patients (n=9)	
Intensity [dB HL]	Moment [nAm]	S.D.	Moment [nAm]	S.D.
40	15.3	7.1	-	-
50	16.4	6.9	13.9	9.3
60	16.7	6.1	25.6	22.6
70	18.8	8.7	36.0	28.0

Table 2: *Mean dipole moments of N100m ECD in normal subjects and patients (right-ear stimulation).*

a) Left hemisphere.

	Normal subjects (n=9)		Patients (n=6)	
Intensity [dB HL]	Moment [nAm]	S.D.	Moment [nAm]	S.D.
40	14.2	6.5	-	-
50	14.2	4.0	14.8	8.3
60	18.2	8.5	27.9	10.6
70	16.8	6.0	35.5	13.5

b) Right hemisphere.

	Normal subjects (n=9)		Patients (n=6)	
Intensity [dB HL]	Moment [nAm]	S.D.	Moment [nAm]	S.D.
40	12.5	4.3	-	-
50	11.4	6.8	11.7	5.5
60	11.5	7.4	20.0	12.1
70	12.0	5.8	20.9	11.7

3.3 Peak latency of N100m

The latency of N100m at lower sitmulus intensity was longer in patients than in normal subjects. The latency decreased as a function of sound intensity in both groups. The degree of decrease was larger in patients than in normal subjects, particularly in the hemisphere contralateral to the stimulated ear (see Tables 3 and 4).

Table 3: *Mean peak latencies of N100m ECD in normal subjects and patients (left-ear stimulation).*
a) Left hemisphere.

	Normal subjects (n=9)		Patients (n=9)	
Intensity [dB HL]	Latency [ms]	S.D.	Latency [ms]	S.D.
40	127.0	23.6	-	-
50	108.4	19.0	171.3	43.7
60	97.3	21.5	124.9	20.4
70	101.6	36.2	108.8	15.1

b) Right hemisphere.

	Normal subjects (n=9)		Patients (n=9)	
Intensity [dB HL]	Latency [ms]	S.D.	Latency [ms]	S.D.
40	111.7	16.2	-	-
50	103.7	17.2	153.5	23.5
60	92.8	16.5	98.2	11.2
70	90.7	21.3	87.3	11.1

Table 4: *Mean peak latencies of N100m ECD in normal subjects and patients (right-ear stimulation).*
a) Left hemisphere.

	Normal subjects (n=9)		Patients (n=6)	
Intensity [dB HL]	Latency [ms]	S.D.	Latency [ms]	S.D.
40	103.4	15.2	-	-
50	102.1	17.0	148.2	23.8
60	90.8	17.9	102.3	10.9
70	84.4	19.9	92.8	7.0

b) Right hemisphere.

	Normal subjects (n=9)		Patients (n=6)	
Intensity [dB HL]	Latency [ms]	S.D.	Latency [ms]	S.D.
40	120.4	19.2	-	-
50	115.5	21.2	154.2	26.5
60	107.8	20.5	107.2	9.6
70	97.2	19.8	102.7	7.4

4 Discussion

The results for normal subjects in this study confirm previous neuromagnetic findings of decreased N100m latency and increased peak amplitude as sound intensity is increased up to 60 or 70dB [1,2]. However, the results for our patients, differed from those for normal subjects in that they included abrupt changes in amplitude and latency. Although there were large differences in age between normal subjects and patients in the present study, a previous report suggested that N100m amplitude was not affected but that the latency was decreased by aging [3]. Thus, the difference observed in this study may not be due to age difference between the two groups, but may be due to inner-ear damage in the patients group.

We observed excessive activity in the auditory cortex at high stimulus intensities in patients with loudness recruitment. The present study may be the first to have determined the cortical responses related to loudness recruitment. Neuronal activities participating in the N100m response may be involved in cortical processing of loudness sensation, and measurement of AEF should be useful for evaluation of loudness recruitment, a very common subjective symptom encountered in patients with inner ear hearing loss.

Acknowledgements

This study was supported by Grants-in-Aid for Scientific Research (B)12470355 and (C)11671677 from the Japan Ministry of Education, Science and Culture, and Health Science Research Grant for Research on Eye and Ear Sciences, Immunology, Allergy and Organ Transplantation from the Japan Ministry of Health and Welfare.

References

[1] J.P. Vasama, J.P. Mäkelä, S.O. Tissari, and M.S. Hämäläinen, "Effects of intensity variation on human auditory evoked magnetic fields", *Acta Otolaryngol (Stockh)* **115**, 616-621, 1995.

[2] C. Pantev, M. Hoke, K. Lehnertz and B. Lütkenhöner, "Neuromagnetic evidence of an amplitopic organization of the human auditory cortex", *Electroencephalography and clinical Neurophysiology* **72**, 225-231, 1989.

[3] E. Pekkonen, M. Huotilainen, J. Virtanen, J. Sinkkonen, T. Rinne, R.J. Ilmoniemi, and R. Näätänen, "Age-related functional differences between auditory cortices: a whole-head MEG study", *NeuroReport* **6,** 1803-1806, 1995.